THE PLANT DISEASE REPORTER

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Division of Mycology and Disease Survey
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SUPPLEMENT 170

SOIL FUMIGATION FOR CONTROL OF NEMATODES AND OTHER SOIL-INHABITING ORGANISMS

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Plant Industry Station Beltsville, Maryland

SOIL FUMIGATION FOR CONTROL OF NEMATODES AND OTHER SOIL-INHABITING ORGANISMS

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The purpose of soil fumigation is to control soil-inhabiting organisms that injure the roots of plants or otherwise interfere with the growth of a crop. The practice aims, in some measure, to accomplish below ground what spraying and dusting accomplishes above ground. Soil fumigation is not a recent innovation but has been used, to a limited extent, for many years. Certain factors, especially the high cost of the materials and the difficulty of applying them effectively, have restricted the practice largely to greenhouses, seed beds, and field areas of small size. Fumigating land on a large scale is, for the most part, a recent development and was made possible by the introduction of new fumigants moderate in cost and better suited to large-scale applications.

The most effective chemicals are those that, through volatilization or chemical reaction, give off toxic fumes which diffuse through the soil. Because the fumes diffuse to only a short distance from the point of application, volatile liquids are injected into the soil at closely spaced intervals. Solids usually are applied in powdered or granular form and mixed with the soil mechanically. Chemicals capable of killing such soil-borne organisms as nematodes, fungi, insects, and weed seeds are very likely to injure the roots of plants, hence fumigants are applied before the crop is planted, and an interval must elapse between application and planting to allow time for the chemicals to lose their toxic properties or for the fumes to escape into the air.

CHEMICALS FOR DISINFESTING SOIL

Dichloropropene, Ethylene dibromide, Chloropicrin, and Methyl bromide

The best known and most widely used soil fumigants are composed of or have as the principal active ingredient one of the following chemical compounds: 1,3-dichloropropene, 1,2-dibromoethane (ethylene dibromide), trichloronitromethane (chloropicrin), and bromomethane (methyl bromide).

General characteristics.--Dichloropropene is not available in pure form. The soil fumigant known as "D-D" (see Table 1) is a dark colored volatile liquid said to be a mixture composed of about equal parts 1,3-dichloropropene and 1,2-dichloropropane with small quantities of other chlorinated compounds. "Dowfume N" is of similar composition. Ethylene dibromide is a commercial product used for various purposes and the liquid is available in more or less pure form. As a soil fumigant it is mixed with some diluent to facilitate more accurate application of small dosages. Chloropicrin (tear gas) is a liquid at ordinary temperatures and usually it is applied to the soil without diluting. Methyl bromide, a widely used fumigant, is a gas at ordinary tempera-

tures (boiling point about 40° F.) and for soil fumigation it is mixed with some diluent with a higher boiling point in order that it may be handled and applied as a liquid.

The above mentioned chemical compounds are insoluble, or only slightly soluble, in water, and, when diluted, some organic solvent is used such as naphtha, mineral spirits, or xylene.

Dichloropropene mixtures and ethylene dibromide are the soil fumigants suited to large-scale application. Because chloropicrin and methyl bromide require measures for confining the fumes in the soil, such as placing over the treated area a gas-impervious cover or sprinkling the surface with water, the use of these fumigants is restricted largely to greenhouses and seed beds or field areas of small size where water is available. Methyl bromide requires careful attention to measures for confining the fumes in the soil but it is not highly toxic to plants and mixtures containing this chemical are useful in greenhouses and in other situations where a short interval between application and planting is an important consideration.

Efficacy as nematocides.--For controlling most nematodes, including the root-knot nematode, dichloropropene mixtures, ethylene dibromide, chloropicrin, and methyl bromide are all effective when properly applied. For cyst-forming species, such as the sugar-beet nematode and the golden nematode of potatoes, dichloropropene mixtures have given the best results.

Efficacy as fungicides.--For controlling fungi chloropicrin is by far the most effective. The dichloropropene mixtures are slightly to moderately fungicidal and, at high rates of application, certain of the mixtures containing methyl bromide are reported to be effective against some kinds of fungi.

Efficacy as insecticides.--All the soil fumigants are toxic to many kinds of soil-inhabiting insects. Ethylene dibromide has proven very effective in controlling wireworms and is used extensively for this purpose in certain Pacific Coast regions.

Efficacy as herbicides.--Chloropicrin is the only soil fumigant now in general use that is sufficiently effective in destroying weed seed to be recommended for this purpose. Under certain conditions, presumably where most of the seeds have started to germinate before the fumigant is applied, moderate to heavy applications of the dichloropropene mixtures are reported as giving a considerable degree of weed control.

Table 1. Soil fumigants sold under trade names

Trade names	Principal active ingredient	Amount By volume %	Amount By weight %	Diluent(s)	Manufacturer
D-D	Dichloropropene	--	--	See text	Shell Chemical Corp.
Dowfume N	do	--	--	See text	Dow Chemical Co.
Dowfume W-40	Ethylene dibromide	--	40	Naphtha	do
Dowfume W-10	do	10	--	do	do
Garden Dowfume	do	5	--	do	do
Iscobrome D	do	10	--	do	Innis, Speiden & Co.
Soilfume 60-40	do	20	42	do	Westvaco Chlorine Products Corp.
Soilfume 80-20	do	10	24	do	do
Bromofume-40	do	--	40	do	Eston Chemicals, Inc.
Bromofume-20	do	--	20	do	do
Bromofume-10	do	--	10	do	do
Larvacide	Chloropicrin	--	--	None	Innis, Speiden & Co.
Dowfume G	Methyl bromide	10	--	Carbon tetrachloride and ethylene dichloride	Dow Chemical Co.
Iscobrome No. 1	do	15	--	Xylene	Innis, Speiden & Co.

Carbon disulfide

Carbon disulfide has been used to a limited extent as a soil fumigant for many years. In this capacity it is slightly to moderately fungicidal and fairly effective against many soil inhabiting insects and most nematodes, but the fumes are exceedingly inflammable and carbon disulfide is being replaced as a soil fumigant by other materials comparable in cost, equally effective, and less hazardous to handle.

Formaldehyde

Water solutions of formaldehyde (formalin or formaldehyde solution) are used to some extent for treating potting soil in small quantities or seed beds of small size. Formaldehyde is effective in controlling many fungi, including those causing "damping off" of seedlings, but it is not very effective against the root-knot nematode. The fumes do not diffuse very freely and formaldehyde in solution is usually mixed with the soil mechanically or applied to the surface as a drench.

Uramon and Cyanamid

Uramon (urea) and cyanamid (calcium cyanamide), two nitrogenous compounds used in the fertilizer trade, are available in powdered or granular form and a combination of the two, when properly applied and mixed with the soil is effective in killing the root-knot nematode, fungi, and weed seed. While perhaps these materials should not be regarded as soil fumigants, they owe their effectiveness, in part at least, to the liberation of ammonia.

Precautions

Most soil fumigants are corrosive to metals, some of them extremely so, and applicators should be emptied and cleaned immediately after use, following the manufacturer's directions.

All fumigants containing methyl bromide should be stored in a cool place. The containers should be full or nearly so and they should be absolutely tight, otherwise the methyl bromide will escape as a gas, leaving only the diluent.

Fumigants containing naphtha as a diluent are inflammable mixtures and precautions should be taken to avoid igniting the fumes by fire or sparks. Dichloropropene mixtures (i.e., "D-D" and "Dowfume N") and mixtures where xylene is used as a diluent (i.e., "Iscobrome No. 1") are inflammable but the fumes are not easily ignited. The fumes from chloropicrin and "Dowfume C" are not inflammable.

All soil fumigants are toxic to humans and animals, at least to some degree, but none are dangerous to the operator when properly handled.

The manufacturer's directions will provide information regarding any special precautions that should be taken when handling particular fumigants. The following precautions should be taken with all soil fumigants:

1. Avoid prolonged breathing of the fumes even though they may not be irritating or have a pronounced or distinctive odor.

2. Do not allow the liquids to remain in contact with the skin. Wash off promptly with soap and water and leave the exposed area open to the air for a short time.

3. If the liquids are spilled on clothing, remove the garment, including shoes or gloves, without delay. Usually it is not advisable to wear gloves.

4. Never, under any circumstances, take the risk of getting the liquids into the eyes or mouth.

The Cost of Soil Fumigants and Where They may be Obtained

Mixtures containing dichloropropene and those containing ethylene dibromide are the least expensive of the soil fumigants now in general use. In quantities of from 1 to 50 gallons, D-D, for example, costs from about $1.60 to about $6.00 per gallon (16 to 60 cents per pound), depending on the amount purchased. Mixtures containing ethylene dibromide are more or less comparable to D-D in cost, the price varying with the amount of ethylene dibromide contained in the different mixtures and with the diluent used. The cost of mixtures containing methyl bromide is usually somewhat higher than of those containing ethylene dibromide. Chloropicrin is the most expensive, the cost, in quantities of from 1 to 50 gallons supplied in cylinders, varying from about $11.00 to about $14.00 per gallon (80 cents to $1.00 per pound.)

When supplied in quantities for large-scale application the price of most soil fumigants is lower than the minimum figures given above. Most large-scale applications are made on a custom basis at a per acre cost ranging from about $30.00 to $50.00, the price varying with the fumigant used and the size of the area.

In many parts of the country soil fumigants may be obtained through the manufacturer's agents or local representatives and disbributors. In regions where soil fumigation has become a common practice, soil fumigants are stocked by some of the retail seed stores. Where such service is not available the materials may be obtained direct from the manufacturers. The agencies from which soil fumigants are purchased may sell applicators also or, in any event, they should be able to provide information as to where such equipment may be obtained.

Companies that manufacture or market the soil fumigants listed in Table 1

Innis, Speiden & Co., 117 Liberty St., New York 6, N. Y.
Shell Chemical Co., 100 Bush St., San Francisco 6, Calif.
Dow Chemical Co., Midland, Mich.
Westvaco Chlorine Products Corp., 405 Lexington Ave., New York, 17, N. Y.
Eston Chemicals, Inc., 3100 East 26th St., Los Angeles 23, Calif.

Companies that manufacture or market hand applicators

Innis, Speiden & Co., 117 Liberty St., New York 6, N. Y.
Mack's Anti-weed Gun, 823 Chicago St., Caldwell, Idaho
Hartsville Chemical Co., Hartsville, S. C.

The above lists are not necessarily complete. They are furnished for the information of the reader with the understanding that no discrimination is intended and no guarantee implied either with respect to the reliability of the companies or the quality of their products.

FUMIGATING COMPOST AND POTTING SOIL

Using Chloropicrin, Methyl bromide, Ethylene dibromide, or Dichloropropene Mixtures

The soil should be finely pulverized and fairly moist with the moisture evenly distributed. Fumigants will not give the best results when soil is on the dry side. The most effective procedure is to place the soil in a tight container which should be full, with no air space between the top of the soil and the cover. The next best arrangement is to have the soil in a bin with tight bottom and sides. After the fumigant is applied the exposed top surface is sprinkled with water and covered with some suitable material (see page 182). Soil can be treated in open piles with fairly satisfactory results but the fumigant will not be quite so effective, especially against organisms that are difficult to kill such as certain fungi and weed seeds, as when the soil is more tightly enclosed.

Small quantities of compost or potting soil can be treated without special equipment for applying the fumigant but for larger quantities in bins or open piles a hand-operated applicator of the spot-injection type (see page 179) will be needed.

Fumigating in closed containers.--The following is suggested as a procedure that may be followed when soil is fumigated in a container.

We will assume that the container to be used is a steel drum, open at one end, about 21 or 22 inches in diameter, and 3 feet long. A drum of these dimensions holds about 7-1/2 cubic feet of soil or slightly more than 6 bushels. Set the drum on end and place soil in the bottom to a depth of 6 inches. Pour over the surface of the soil, distributing it in several evenly spaced spots, 20 cubic centimeters (about 1-1/2 tablespoonfuls) of the fumigant and immediately place over this an additional 12 inches of soil. Make another application and repeat until the drum is full. This will require 3 applications and the last will be about 6 inches from the top. Level off the surface, sprinkle with water, and cover to make the top as nearly gas-tight as possible. The above rates of application should be adequate for chloropicrin, dichloropropene mixtures, fumigants containing 10 to 15 percent by volume of methyl bromide, and those containing 10 percent by volume of ethylene dibromide. If the operation is carried on in the open, if a breeze is blowing, and if the operator works on the windward side, chloropicrin can be applied in this manner without undue physical discomfort. When using chloropicrin it is advisable to measure dosages in advance, placing each in a corked vial, or to pour from a Larvacide dispenser bottle regulating the dosages by the graduations on the label.

Fumigating in bins or open piles.--The following is suggested as a procedure that may be followed when soil is fumigated in bins or open piles. The pile should be rectangular in shape, flat on top, and with the sides at a steep even slant. The spacing of injection points and the rate of application can be regulated more conveniently if the depth of the soil in the bin or pile is about 1 foot or some multiple thereof. Mark the top surface of the soil lengthwise and crosswise with marks 10 inches apart and stagger the injections (see diagram, page 180). Apply chloropicrin, dichloropropene mixtures, or fumigants containing 10 percent by volume of ethylene dibromide at the rate of 3 cubic centimeters (about 1 teaspoonful) per injection: apply fumigants containing from 10 to 15 percent by volume of methyl bromide at the rate of 6 to 8 cubic centimeters (about 1-1/4 to 1-1/2 teaspoonfuls) per injection. When the soil in the bin or pile is 1 foot deep, inject the fumigant to a depth of 6 inches, when the soil is 2 feet deep make one set of injections to a depth of 18 inches and another set to a depth of 6 inches. If an applicator with a long soil probe is not available, make the first set of injections before the upper 12-inch layer is added. When the soil is in an open pile make additional injections at the sides, inserting the probe of the applicator obliquely to a depth of 6 inches. Smooth the exposed surfaces with a hand rake, sprinkle thoroughly, and cover with the most suitable material available (see page 182).

Using Formaldehyde

Formaldehyde is suitable for treating compost and potting soil in small quantities and it is effective in controlling many fungi, including those causing "damping off" of seedlings, but it is not sufficiently effective in controlling the root-knot nematode to be recommended for this purpose.

Mix 1 part of commercial formalin or formaldehyde solution with 5 or 6 parts of water and sprinkle 30 cubic centimeters (about 2-1/2 tablespoonfuls) of this dilution over, and thoroughly mix it with, each bushel of soil. If the soil is then spread in thin layers (3 inches deep or less) or placed in shallow flats, seed may be planted 24 hours after treatment. Heavy soils should be lightened before treating by adding organic matter, otherwise the seeds or seedlings may be injured. Formaldehyde can be applied also as a dust and several formaldehyde dusts are on the market. The dust is mixed with the soil according to directions on the container, after which the soil should be thoroughly watered. Seed may be sown immediately but at least 3 days should elapse before cuttings or transplants are set.

Formaldehyde gas is toxic to plants and the fumes, in any appreciable concentration, should not be allowed to escape into a greenhouse where plants are growing.

Aeration

In most instances fumigated soil must be aerated before it is safe to use for sowing seed or setting transplants. The rate at which aeration takes place depends on so many different factors that it is impossible to be definite about the time required. Aeration is fastest in dry soil and at high temperatures and it can always be hastened by stirring the soil or spreading it out to increase the surface exposed to the air. When methyl bromide is used the ordinary procedure of handling the soil will provide all the aeration necessary. Soil treated with chloropicrin should not be used as long as any odor of the fumigant can be detected. When a dichloropropene mixture has been employed it is not necessary to wait until all odor of the fumigant has disappeared but it is safer to wait until the odor is faint, especially if the soil is to be used for transplants.

Soil fumigated with chloropicrin must not be moved into a greenhouse where plants are growing until aeration is complete. Soil treated with fumigants containing methyl bromide or with those containing dichloropropene can be moved from the bin or pile directly to a greenhouse and placed on benches or in flats without previous aeration and without endangering plants growing in the same house. Presumably the same can be said of soil fumigated with ethylene dibromide though little information is available on this point.

FUMIGATING GREENHOUSE BEDS, SEED BEDS, AND FIELD AREAS OF SMALL SIZE

Application Equipment

Seed beds, flower beds, and other small outdoor areas not exceeding a few hundred square feet can be treated without special equipment by punching holes in the soil and pouring in measured quantities of the fumigant. This procedure is suggested for use in the open, not in greenhouses or other enclosures, and it is not recommended as a method for applying chloropicrin in any situation. For treating larger areas or for applying fumigants in greenouses, an applicator will be needed.

Spot-injection applicators resemble huge hypodermic needles and inject small quantities of the fumigant into the soil at spots. Several hand applicators of this type are on the market and they are suitable for treating small areas. Continuous-flow applicators inject the fumigant into the soil in one or more continuous subsurface streams. Small-sized applicators of this type are not yet generally available but at least one kind, delivering two parallel streams simultaneously, has been manufactured and sold in limited numbers. Such applicators require more motive power than that provided by one operator. They can be pulled by additional operators, by a draft animal, or by a small tractor. Power-driven applicators of similar design, suitable for use in large greenhouses or for treating field areas of moderate size, have been built and used experimentally (see page 176).

Preparing the Soil

The soil is prepared in the same manner as for planting a crop. It should be moderately loose and reasonably free from clods, lumps, and undecomposed crop residues. Roots of the preceding crop should be removed or allowed time to decay. If barnyard manure or compost is to be mixed with the soil this should be done before the fumigant is applied. When a rotary tiller is used the land should be prepared a few days in advance to allow time for the soil to settle. Fumigants perform best in soil that is fairly moist. Results will be unsatisfactory when fumigants are applied to dry soil. Except under wet conditions, moderate rain following application is beneficial. The temperature of the soil should be above 40° F., preferably between 60° and 85° F.

Applying the Fumigant

The fumigant should be placed about 6 inches below the surface of the soil. Where application is by spot injections, mark the area lengthwise and crosswise forming small squares like a checkerboard. Starting at one side, make injections along the first mark at the

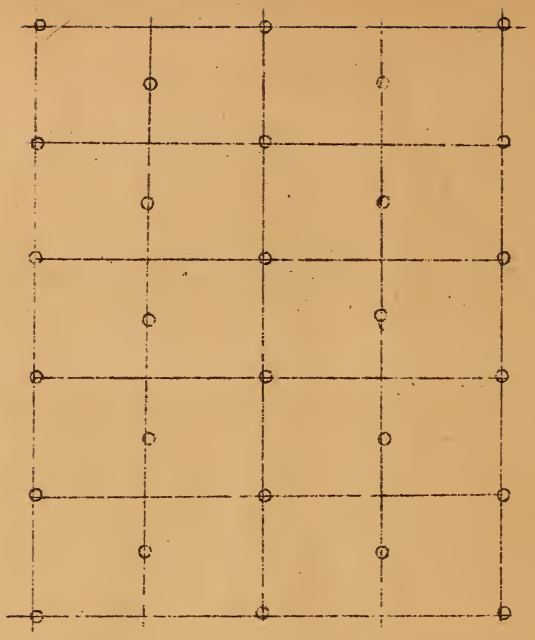

Diagram showing arragnement of application points

points where the cross marks intersect, along the second mark midway between where the cross marks intersect, etc. (see diagram). Staggering the injections in this manner aids in giving the greatest possible coverage. In the following discussion, figures designating the spacing of injections refer both to the distance between rows of injection points and the distance between injection points in the row.

Proper spacing between injections depends on the kind of fumigant, the organisms to be controlled, and the kind of soil. In general better coverage is obtained when a given rate per unit area is applied in small dosages closely spaced than when the same rate is applied in larger dosages more widely spaced.

When fumigating seed beds and similar small areas, a high degree of control, often of a variety of different organisms, is likely to be more important than the cost of the fumigant. The following rates of application therefore are somewhat higher than those usually employed for large-scale applications. The rates are based primarily on requirements for controlling the root-knot nematode but they should be adequate for most of the organisms against which the particular fumigants are effective and for all except very heavy clay soils. The amounts per injection may be decreased slightly for light sandy soils.

When fumigating very heavy clay soils, decrease the spacing between injection points by about 2 inches without decreasing the amounts per injection.

Fumigants should not be applied to the area occupied by the root systems of living plants. One can estimate about how close to such plants it is safe to apply fumigants by remembering that, when injected at the rates ordinarily used, the fumes will diffuse through the soil to a distance of not more than about 10 inches.

Dichloropropene mixtures.--Space injections 12 inches apart and apply 4 to 5 cubic centimeters (about 3/4 to 1 teaspoonful) per injection. This is equivalent to 46 to 57 gallons per acre.

Ethylene dibromide.--When using mixtures containing 10 percent by volume (about 20 percent by weight) of ethylene dibromide, space injections 12 inches apart and apply 5 to 6 cubic centimeters (about 1 to 1-1/4 teaspoonfuls) per injection. This is equivalent to 57 to 69 gallons per acre. When controlling wireworms is the only objective apply 3 cubic centimeters (about 1/2 teaspoonful) per injection. This is equivalent to 34 gallons per acre. Use twice the above amounts when applying mixtures containing 5 percent by volume (about 10 percent by weight) of ethylene dibromide and half these amounts when applying mixtures containing 20 percent by volume (about 40 percent by weight) of ethylene dibromide.

Chloropicrin.--Space injections 10 inches apart and apply 2.5 to 3 cubic centimeters (about 1/2 teaspoonful) per injection. This is equivalent to 41 to 50 gallons per acre.

Methyl bromide.--When using mixtures containing 10 to 15 percent by volume of methyl bromide, space injections 10 inches apart and apply 5 to 6 cubic centimeters (about 1 to 1-1/4 teaspoonfuls) per injection. This is equivalent to 82 to 99 gallons per acre. (Applications of 7 to 8 cubic centimeters per injection are reported to be effective in controlling some kinds of fungi.)

Formaldehyde.--Small areas may be treated by applying formaldehyde as a drench. To 1 part commercial formalin or formaldehyde solution add 50 parts of water and apply 1/2 to 1 gallon of this dilution to each square foot of soil. The treated area should be covered for 2 days with some material that will help confine the fumes (see following section). This treatment is reported effective for controlling many kinds of fungi but it is not effective against the root-knot nematode.

Procedure following Application

After the fumigant has been injected (except where formaldehyde is used as a drench) the area should be made as flat and smooth as possible. Small areas can be smoothed with a hand rake. For most soils rolling is beneficial.

If chloropicrin or methyl bromide was used, sprinkle with water, after smoothing the soil, wetting the surface to a depth of an inch or more. This so-called "water seal" should be applied promptly; if delayed for as long as 2 hours after the fumigant is injected much of the gas will escape. Dichloropropene mixtures and ethylene dibromide do not ordinarily require a "water seal" but under hot, dry conditions or where there is a surface layer of dry soil the action of any fumigant will be improved by sprinkling.

When using chloropicrin or methyl bromide in seed beds and other small areas where a high degree of sterilization is desirable, the area should be sprinkled and then covered with some suitable material. Specially treated tarpaulins and glue-coated craft paper have the advantage of being comparatively gas tight. Light weight roofing paper can be used to advantage over long narrow seed beds. Untreated canvas, cloth sacks, paper, peat moss, etc., serve to retard evaporation and hold the moisture at the surface of the soil. Any covering material that will absorb water should be sprinkled after it is applied.

The soil should remain undisturbed (and the covering, when one is used, should remain in place) for at least 2 days after applying chloropicrin or methyl bromide and at least 4 days after applying ethylene dibromide or a dichloropropene mixture.

Interval between Application and Planting

The interval that must elapse after a fumigant has been injected and before it is safe to plant a crop is exceedingly variable and depends on many factors such as the fumigant used, the rate of application, the kind of soil, the condition of the soil (especially temperature and water content), and the crop to be planted. For most soils of moderate moisture, where soil temperature is not below 60° F., and where the rate of application is not exceptionally high, the interval for methyl bromide is 2 to 3 days, for chloropicrin and ethylene dibromide 1 to 2 weeks, for dichloropropene mixtures 2 to 3 weeks (see also page 188). If the fumigant has a fairly pronounced odor, an indication of the amount of gas remaining can be obtained by smelling a handful of soil secured 6 inches or so below the surface. The area should not be planted as long as any odor of formaldehyde or of chloropicrin remains. With dichloropropene mixtures it is not necessary to wait until all odor of the fumigant has disappeared but to be on the safe side one should wait until the odor is faint especially if the

land is to be used for transplants. Aeration can be hastened by tillage for which purpose a rotary tiller is well adapted. When conditions permit, land should be treated the preceding autumn for crops that must be planted in early spring.

Fumigating Greenhouse Benches

Raised benches in greenhouses are treated in the same manner as ground beds and other small areas and with about the same or slightly heavier rates of application (see page 181). Except where formadehyde is applied as a drench, the soil should be moderately moist throughout with no dry corners or pockets. If the soil has become dry, wet thoroughly and allow time for excess water to drain away. Inject the fumigant to a depth equal to about half the depth of the soil in the bench, smooth and firm the surface, sprinkle with water, and cover with some suitable material (see page 182).

Chloropicrin and methyl bromide are commonly used for fumigating greenhouse benches. Except for the possible objection that a somewhat longer interval may be required between application and planting, there appears to be no reason why ethylene dibromide and the dichloropropene mixtures should not be suitable for this purpose.

When using chloropicrin or formaldehyde all plants growing in the same section must be removed and partitions between this and adjoining sections sealed. During warm weather when the ventilators can remain open, dichloropropene mixtures can be applied to soil in greenhouses without much danger of injuring plants growing in the same section, and methyl bromide can be applied with even less danger. Not much information is available about the use of ethylene dibromide in greenhouses but probably no greater risks will be involved than with the dichloropropene mixtures.

Treating Seed Beds with Uramon and Cyanamid

A mixture of 2 parts uramon and one part cyanamid is effective for destroying weed seeds and controlling the root-knot nematode and fungi in seed beds. Plow and disk or spade and rake the area to be treated. Apply the chemicals at the rate of one pound uramon and one-half pound cyanamid (1-1/2 pounds of the mixture) to each square yard of area. Broadcast about two-thirds of the required amount evenly over the surface and work in to a depth of 4 to 6 inches, mixing the chemicals thoroughly with the soil. Broadcast the remaining one-third and work into the surface lightly with a hand rake. The chemicals should be applied at least 60 days, preferably 90 days, before seed is sown. In most instances this means preparing the land and applying the chemicals the preceding autumn. Both uramon and cyanamid contain nitrogen hence little or no nitrogen need be applied as fertilizer when the treated area is planted. This method was developed primarily for treating to-

bacco plant beds and it is suited to the light sandy loam soils of the eastern coastal plain region. The ammonia liberated by the chemicals may have an undesirable effect on the physical properties of heavy soils.

Fumigating Hill and Planting Sites

Annual crops grown in widely spaced hills such as watermelons, trees such as peaches and figs, and ornamental shrubs such as gardenias, can be protected against root-knot-nematode injury, at least during early stages of growth, by fumigating the planting sites. This practice has been tested experimentally at Tifton, Georgia, and the following suggestions are based on procedures and rates of application that gave good results in the Norfolk sandy loam soils of the Tifton region.

For watermelons, locate and mark the position of each hill, make one injection of the fumigant at each of these spots, and, after a week or two, plant the seed at the place where the fumigant was applied. A dichloropropene mixture or chloropicrin applied at the rate of 2 to 3 cubic centimeters per injection, or a fumigant containing 15 percent methyl bromide applied at the rate of 30 cubic centimeters per injection, gave satisfactory results at Tifton. Unless the fumigant is held in the soil by rains following application, an interval of 2 weeks between application and planting is adequate for a dichloropropene mixture and an interval of 1 week for chloropicrin or methyl bromide. Chloropicrin and methyl bromide have the disadvantage that an area about 2 feet in diameter, centering on the point of injection, must be sprinkled with water immediately after injecting the fumigant.

For trees such as peaches and figs, the fumigant is applied to a circular area about 6 feet in diameter following the same procedure as for any other small-scale field application (see page 179, 180). After an interval of 2 to 3 weeks a tree is set in the center of each treated area, care being taken that soil returned to the hole and placed around the roots be from the treated, not from the surrounding untreated, area. A dichloropropene mixture applied with a spot-injection applicator at the rate of 3 cubic centimeters per injection, with injections spaced 17 inches apart, gave good results at Tifton. Closer spacing probably would be advisable in heavier soils. The Tifton experiments did not include ethylene dibromide but there is no reason to believe that this fumigant would not have given good results. Applying the fumigant with a power-driven applicator to strips about 6 feet wide, the strips being so spaced that a row of trees will be set through the middle of each, seems to be a logical procedure when setting large orchards.

Precautions to Avoid Recontamination of Treated Areas

Treated areas may become recontaminated in various ways depending on the conditions and the disease organisms involved. When treatment is for control of such microscopic organisms as nematodes and fungi, garden tools and other tillage implements, if previously used on infested land, should be cleaned before using on treated areas. Attention should be given also to the possibility of transporting infested soil on shoes or on the feet of work animals, especially during wet weather. Trenches around seed beds and similar outdoor areas may prevent water from washing over them during heavy rains, a precaution that is quite important, in some situations, when soil is treated in autumn. Where transplants, bulbs, tubers, etc., are used, soil treatment may be of little avail if planting stock is infected.

Table 2. Conversion of measurements

1 teaspoon	equals	approx.	5	cubic	centimeters
1 tablespoon	"	"	15	"	"
1 cup	"	"	237	"	" ; 1/2 pint
1 fluid ounce	"	29.6	cubic	centimeters	
1 pint	"	473.2	"	"	
1 quart	"	946.3	"	"	
1 gallon (U. S.)	"	3785.4	"	"	

Table 3. Relationship between the weight and volume of six commonly used soil fumigants

Fumigant	Cubic centimeters per pound	Pounds per gallon
Larvacide	273	14
D-D	378	10
Dowfume N	378	10
Dowfume W-10	522	7.25
Dowfume G	344	11.3
Iscobrome No. 1	456	8.3

Table 4. Amounts of fumigant in cubic centimeters required to treat an area of 100 square feet

Spacing of injections: inches	Cubic centimeters per injection									
	1	2	3	4	5	6	7	8	9	10
8	225	450	675	900	1125	1350	1575	1800	2025	2250
10	144	288	433	577	721	856	1009	1150	1298	1442
12	100	200	300	400	500	600	700	800	900	1000
14	73	147	220	294	367	441	514	588	661	734
16	56	112	169	225	281	337	393	450	506	562

Table 5. Amounts of fumigants in gallons required to treat one acre.

Spacing of injections: inches	Cubic centimeters per injection									
	1	2	3	4	5	6	7	8	9	10
8	23.3	46.5	69.8	93.0	116.3	139.5	162.8	186.0	209.3	232.5
10	16.6	33.1	49.7	66.3	82.8	99.4	116.0	132.6	149.1	162.7
12	11.5	23.0	34.5	46.0	57.6	69.0	80.6	92.1	103.6	115.1
14	8.4	16.9	25.4	33.8	42.3	50.7	59.2	67.6	76.1	84.5
16	6.5	13.0	19.9	25.9	32.4	38.8	45.3	51.8	58.2	64.7

LARGE-SCALE SOIL FUMIGATION

Soil fumigation has become a regular practice in the pineapple fields of Hawaii and is becoming so in California and other western States where many thousands of acres are treated annually. Dichloropropene mixtures and ethylene dibromide are the fumigants used and a greater part of this area is treated primarily for controlling one or the other or a combination of two major pests: the root-knot nematode and wireworms. The practice appears to be coming into use in Florida but as yet on a more moderate scale. In connection with their program for controlling the golden nematode of potatoes, the State of New York, in cooperation with the U. S. Department of Agriculture, fumigated about 1500 acres on Long Island during 1946, using a dichloropropene mixture.

Application Equipment

Large-scale applications are made with power-driven applicators of the continuous-flow type that deliver into the soil from 6 to 10 streams simultaneously or with attachments to plows that place the chemical in the bottom of the furrow just in front of the moldboard where it is immediately covered. Applicators consist of a tank to hold the fumigant and a system of tubes to convey it into the soil, the tubes passing down the back edge of narrow cultivator teeth sometimes referred to as chisels. One or more pumps are included in the mechanism and the liquid is delivered under pressure. The chisels are mounted on a horizontal bar or framework capable of being raised and lowered. In some types of applicators the tank, chisels, and delivering mechanism are mounted directly on a tractor while in other types they are carried on a separate vehicle that operates as a trailer.

Applying fumigants on a large scale is usually done on a custom basis by individuals or companies owning power equipment and anyone interested in large-scale operations should make contact with representatives of the companies that produce dichloropropene or ethylene dibromide products.

Preparing the Land

The land should be plowed and harrowed to the consistency of a good seed bed. Disking alone will not work the soil to a sufficient depth. The land should be reasonably free from clods, undecomposed crop residues, and other trash, as such materials create air pockets in the soil that prevent proper diffusion of the gases and collect on the applicator chisels, causing furrows that are not easily filled. The soil should be at least moderately moist though not excessively wet. Land that is in a tillable condition is not too wet to treat. The temperature of the soil should be above 40° F., temperatures between

60° and 85° F. being optimum.

Applying the Fumigant

For most large-scale operations the cost of the fumigant is an important consideration. Unless the crop has a high cash value the rate of application cannot greatly exceed the minimum required to prevent the pests involved from appreciably reducing yield. The rate varies with the fumigant used, the pests to be controlled, and the type and condition of the soil. Against wireworms, 20 gallons per acre of a fumigant containing 10 percent ethylene dibromide by volume are reported as usually giving good results. For controlling the root-knot nematode, 30 gallons of a fumigant containing 10 percent ethylene dibromide or 20 gallons of dichloropropene mixture per acre are the minimum rates usually recommended. For special conditions, where a high degree of control is needed and where crop values justify the expense, applications up to 40 gallons per acre of either a 10 percent ethylene dibromide mixture or of a dichloropropene mixture may be desirable. The dichloropropene mixtures are recommended for cyst-forming species such as the sugar-beet nematode and the golden nematode of potatoes and for these two pests a somewhat higher rate is needed than that used against root-knot. Fall applications of a dichloropropene mixture at the rate of 45 gallons per acre gave good control of the golden nematode of potatoes on Long Island, New York.

For best results the chisels on the applicator should not be spaced farther than 12 inches apart and the fumigant should be injected at a depth of from 6 to 8 inches. Because openings left by the chisels should be filled promptly, a drag or roller is sometimes attached to the applicator. The soil should be left flat, smooth, and compact at the surface and whatever operations are needed to bring the land into this condition should be done promptly after application. When the fumigant is applied by means of an attachment to a plow, harrowing and smoothing must not be long delayed.

Interval between Application and Planting

As already explained (page 182) the interval that must elapse between application and planting varies considerably, depending on the rate of application, the kind and condition of the soil, and other factors. The following intervals are suggested as adequate for average conditions in the Atlantic Coastal Plain region and in the southwestern States where most of our information on the matter has been obtained. With conditions especially favorable for rapid escape of the fumes, such as sandy soil, dry soil, and high soil temperatures, somewhat shorter intervals may be sufficient while with conditions unfavorable, such as heavy soil, wet soil, and low soil temperature, considerably longer intervals may be necessary. Where conditions in autumn permit, it is recommended that applications be made at this

time for crops that must be planted in early spring.

Dichloropropene mixtures.--In the southeastern States the interval varies from about 14 days for 20-gallon-per-acre applications to about 30 days for 50-gallon-per-acre applications; in the southwestern States from 8 to 10 days for 20-gallon-per-acre applications to 20 to 25 days for 50-gallon-per-acre applications.

Fumigants containing 10 percent by volume of ethylene dibromide.--In the southeastern States the inverval varies from about 8 days for 20-gallon-per-acre applications to 18 days for 50-gallon-per-acre applications; in the southwestern States from about 6 days for 20-gallon-per-acre applications to about 12 days for 50-gallon-per-acre applications.

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